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ANALYSING THE EFFECT OF BUILDING ORIENTATION, VARIED WWR AND BUILDING HEIGHT ON SOLAR HEAT GAIN AND INTERNAL TEMPERATURE OF UNIVERSITY BUILDING LOCATED IN COMPOSITE CLIMATE OF INDIA

[1]RAJ R NAIR, [2]ANKIT SHUKLA, [3]SIDDHARTH SHEKHAR, [4]ABHISHEK JATAV

[1]Student, Department of Mechanical Engineering, Suresh Gyan Vihar University, Rajasthan, India, Email: rrnair31@gmail.com

[2]Student, Department of Mechanical Engineering, Suresh Gyan Vihar University, Rajasthan, India, Email: ankit250074@gmail.com

[3]Student, Department of Mechanical Engineering, Suresh Gyan Vihar University, Rajasthan, India, Email: siddharth2091@gmail.com

[3]Asst. Professor, Department of Mechanical Engineering, Suresh Gyan Vihar University, Rajasthan, India, Email: jatavabhishek@gmail.com

ABSTARCT

In a composite climatic condition of India like Rajasthan, varying the orientation of building, window-wall ratio (WWR), and building height have a highly influential effect on the buildings. The aim of this research work is to control the solar heat gain and internal air temperature of the building thereby improving the thermal comfort. For achieving this, we have used three energy efficient methods (EEM) which is mentioned above, plus the combined effect i.e. the combination of best results obtained from all the three EEMs. This research work is performed with the help of Building Energy Simulation (BES). From the final result, the combined effect i.e. the combination of 15% WWR, south orientation of building and 25 feet height of building, has shown the best effect in reducing the solar heat gain and internal air temperature and also in improving the thermal comfort. But it has been proved from the study that varying the building height and window-wall ratio and also changing the orientation of building has not shown much improvement in reducing the internal air temperature of the building. At the same time it has shown that, as compared to the base building, 39% annual

reduction in solar heat gain and 8 – 10% annual reduction in fanger PMV is achieved by the combined effect.

KEYWORDS: Building Energy Simulation, Energy Efficient Methods, Fanger PMV, Orientation, Window-Wall Ratio.

1. INTRODUCTION

In the present world energy consumption has become such a issue that a serious attention has to be given. This energy consumption comes under four categories. These include industrial, residential or commercial, transportation and agriculture. Out of these four, residential and commercial sectors are the leading consumer of energy. They are conscientious for between 30 and 40 percent of energy usage **(6).** This sector has been followed by the industrial sector which is another major consumer of energy. If the energy consumption in residential and commercial sector continues to grow at present rate then it is a guaranteed fact that the energy will get exhausted in very near future. This can cause some serious problem for the upcoming generation. In order to conserve the energy for the future generations it is essential that people should be very much aware about how to preserve the energy or how to use the energy wisely. From the studies conducted by the government of India organisations like TERI and BEE, the energy usage of different equipments of the buildings has been understood. These include 60% of the energy usage is from lighting applications, 32% of the energy usage is from air conditioning equipments and 8% usage is from other energy consuming equipments installed in buildings. **(14).** As the research work is based on a university workshop building, the use of air-conditioners or coolers is not a solution for minimising the high degree of heat during summer. A study carried out on a field of reducing the solar heat gain and internal air temperature, it has been found that, changing the orientation by 45° will not show much appreciable effect in reducing the internal air temperature but by varying the orientation by 90° will show reduction in cooling demand before 6:30 in evening **(2).** A study conducted by Shivraj Dhaka in three climatic conditions of India shows that by making the building ECBC acquiescent, 40% reduction in energy consumption can be achieved in case of

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composite climatic condition of India and in case of hot and dry climate 43.1% reduction is achieved whereas in case of warm and humid climatic condition like Chennai 39% reduction is possible **(1).** The most influential factor behind the solar heat gain in buildings is the fenestration system of buildings. Out of the fenestration system, windows are conscientious for 20 – 40% of energy wastage in building **(6).** In a study based on changing the WWR, J.W.Lee has showed that in case of cooling based cities energy load can be highly reduced by keeping 50% WWR on the north face and 25% WWR each on the south, east and west faces whereas in case of heating based cities mounting the windows on the south face of the window is very much beneficial and the WWR should be 25% on each face of the wall. The total building energy load can be highly reduced by slandering the window size up to 25% for each building envelope **(6).** The most optimum value of WWR in case of clear glass of 8 mm thickness is 0.12 whereas in case of RLV glass it has been 0.22. It has also been found that if the WWR value goes beyond the value of 0.45 in case of clear glass and 0.85 in case of RLV glass the energy consumption will be higher **(12).**

The main intention behind this study is to reduce the solar heat gain and internal air temperature thereby improving the thermal comfort of the workshop of a university building with the help of some energy efficient methods such as building orientation, window-wall ratio (WWR), building height and the combined effect of all the three EEMs used in this study.

2. RESEARCH METHODOLGY

2.1 BUILDING LOCATION

The work has been carried out at **Suresh Gyan Vihar University's workshop building** at Jaipur (26.82°, 75.80° and 390 m above sea level). The city preferred for this work is known for its extremely high temperature during summer and extremely low during winter season. In a city like Jaipur, the midday high temperature during the summer time reaches around 44°C and during winter it is about 5°C. This city comes under the composite climate of India. The proper location of this workshop is inside the mechanical department of the university and all the works related to mechanical engineering is carried out in this building such as drilling, milling,

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grinding, welding, foundry works, fitting etc.

The building which has been analysed for this dissertation work is 14 years old and it has been built with a metal steel pitch roof which is unoccupied and has a double brick wall with beam type heavy weight construction. Fig. 1(A) shows the geographic location of the university building and the marked area shows the workshop of the university building. The workshop building selected for this work has a floor to floor height of 7.72 m, opaque door of 2.3m x 1.8m. Windows used in the building are quite ordinary and have a single clear glass of 0.006m thickness. In case of east and south wall of the building, window glass panes are operable to outside whereas it is sliding type in case of north wall and west wall which is the entry side of workshop is free of windows. Iron frames are used for the construction of windows in east and south facing walls whereas windows of the north facing walls are provided with aluminium frames. The method used for the construction of workshop building is analogous to conventional construction practices used in India. The workshop building preferred for our study has four internal partitions which includes the main area, where all the machining operations are carried out, fitting shop, foundry shop and welding shop. The occupancy in this building is based on the time table allotted in the college. The workshop is equipped with thirty machines, twenty-four fans, three fluorescent tube-lights and three exhaust fans.

2.2 TEMPERATURE MEASUREMENT

The internal air temperature of the workshop building is measured for the validation work. The instrument used in this study for measuring the air temperature is analogue thermometer. Fig. 1(D) shows the thermometer used for measuring the internal air temperature. The measurements were made at a constant time interval of one hour. The room air temperature measuring thermometer was suspended 2.3m from the ground level and 2.225m away from the east wall. The air temperature of the workshop building has been taken during the college time at a constant time interval of one hour from June 19 to June 30 for 70 hours.

2.3 MODELLED BUILDING

‘Design Builder’ (version 2.3.5.036) has been used for simulating the model of the building block considered for the

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study. In this software all information of the base building block is given in the form of input. These include building envelope (roof, wall and glazing) properties, occupants' schedule, lighting schedule, equipment (machines and fans) schedule, shading etc. Design Builder can be defined as dynamic simulation software, which have a comprehensive builder graphical interface and use energy plus as a core calculator **(5).**

After providing all the details of actual building block into the simulation model which is created with the help of design builder (version 2.3.5.036), final simulation of building is done. Final simulation is performed with the help of **Energy Plus (Version 6)** building simulation program. Fig. 1(B) and (C) shows the axonometric and top view of the modelled workshop building.

The air temperature which we got from the simulated program is compared with the air temperature which is acquired during the actual measurement. The analogy between the measured and simulated values is found with the help of mean bias error (MBE) and coefficient of variation root mean square error formulas. The simulated and measured values posses a good resemblance if the errors are less than 10 and 15% **(1).** Equations (1) – (4) show the formulas used for finding out the MBE and C_vRMSE.

$$MBE\ (\%) = \frac{\sum_{period} (S-M)_{interval}}{\sum_{period} M_{interval}} \times 100 \qquad (1)$$

where, M → Measured value

S → Simulated value

$$RMSE_{period} = \sqrt{\frac{\sum (S-M)^2_{interval}}{N_{interval}}} \qquad (2)$$

Where, N → number of time intervals (70 hours).

$$A_{period} = \frac{\sum_{period} M_{interval}}{N_{interval}} \qquad (3)$$

Where, A_{period} → mean of measured values

Now, the coefficient of variation of root mean square error value can be found out as:

$$C_v\ (RMSE_{period}) = \frac{RMSE_{period}}{A_{period}} \times 100 \qquad (4)$$

For validating the overall heat transfer coefficient (U-value) of the walls of the building, we have used the formula from ECBC table 4.1 **(15)** and values of

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thermal conductivities of each material is taken from engineering toolbox **(16).**

Resistivity, $R = \frac{\text{thickness (d)}}{\text{conductivity (k)}}$

Total thermal resistance, $R_T = R_{si} + R_t + R_{se}$

Where, R_{si} = resistance of internal surface, R_{se} = resisitance of external surface

$R_t = R_1 + R_2 + \ldots\ldots + R_n$.

Finally, $U = \frac{1}{R_T}$

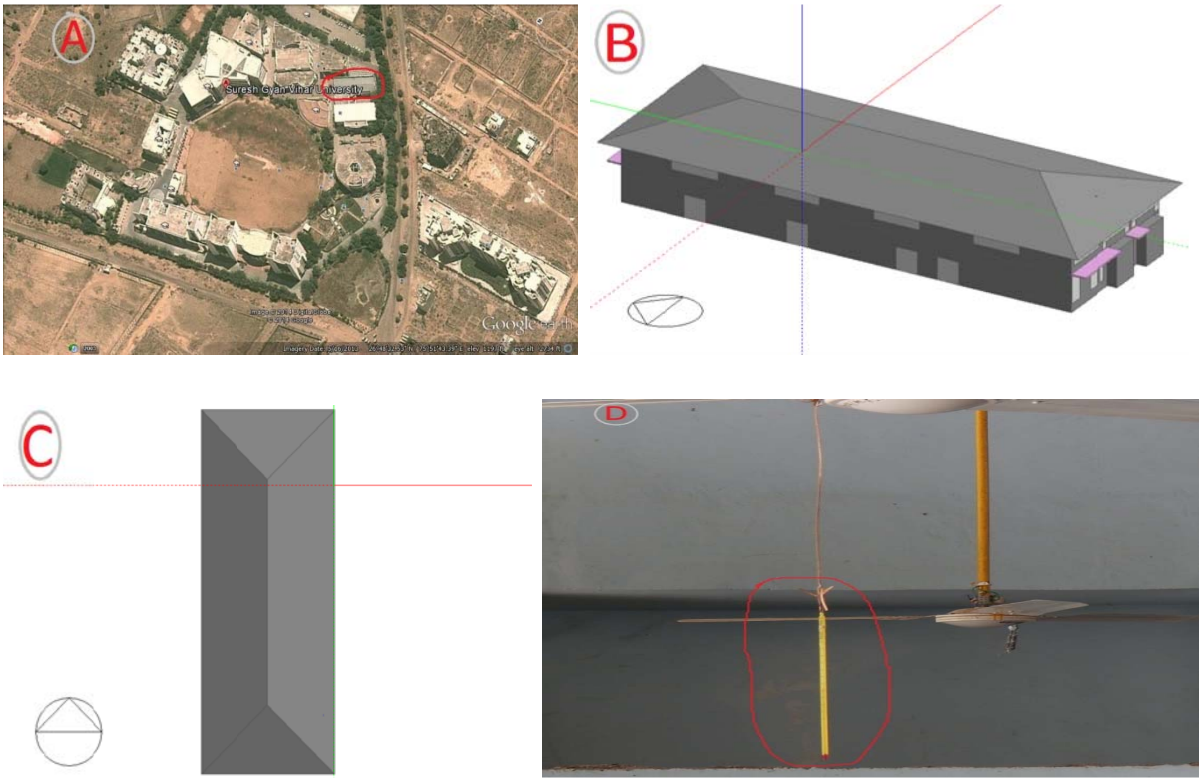

Figure 1: (A) Geographic location of building. (B) Axonometric view of modelled building. (C) Plan view of modelled building. (D) Suspended thermometer for measuring the air temperature

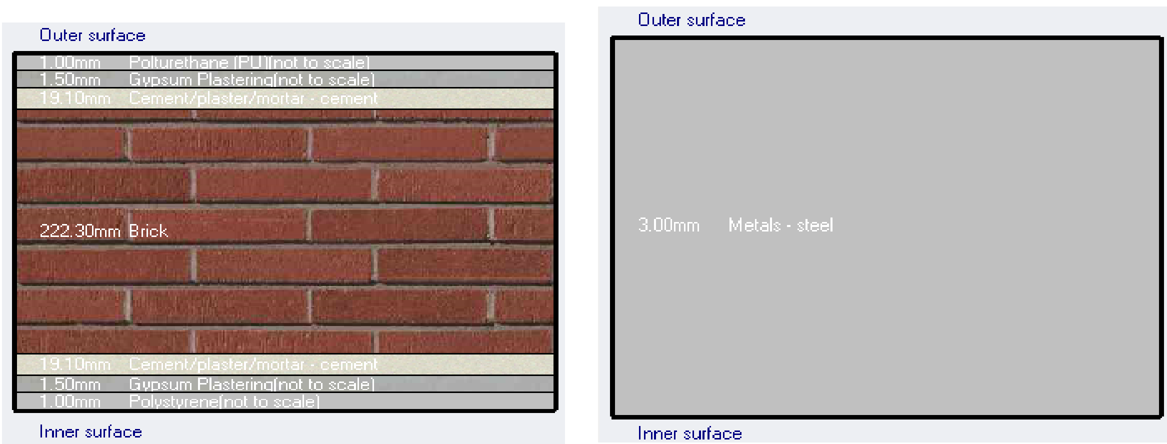

Figure 2: Construction of wall and roof

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Table: 1: Construction details of building

MATERIAL (outermost to innermost layer)	WALL THICKNESS (m)	ROOF THICKNESS (m)	FLOOR THICKNESS (m)
Polyurethane	0.0010	-	-
Gypsum Plastering	0.0015	-	-
Cement	0.0191	-	0.0254
Brick	0.2223	-	-
Cement	0.0191	-	-
Gypsum Plastering	0.0015	-	-
Polystyrene	0.0010	-	-
Metal-Steel	-	0.0030	-
Slate Tiles		-	0.0254
Cast Concrete		-	0.1016
Earth and Gravel		-	0.0762

2.4 ENERGY EFFICIENT METHODS

This research work has been carried out with the help of four main parameters. These include:

- **Window-Wall Ratio (WWR):** In this parameter the ratio of window to wall has been changed three times for each wall of the base building and the effect on base building energy consumption has been checked.
- **Building Orientation (BO):** In this parameter the orientation of building has been changed i.e. east, north, south and the effect on the base building has been checked.
- **Building Height (BH):** With the help of this EEM, the height of base building has been changed five times for checking the energy consumption effect of the building.
- **Combined Effect:** In this case, the combined effect of all the above

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methods has been used in the base building. After taking out the varying results from each parameter, the best one is selected from each and finally that best three effects will be implemented on the base building for bringing out the suitable result.

Table: 2: NOMENCLATURE OF ENERGY EFFICIENT METHODS

METHODS	**NOMENCLATURE**	**FULL**
Original Building	BB	BASE BUILDING
EEM 1	WWR	WINDOW-WALL RATIO
EEM 2	BO	BUILDING ORIENTATION
EEM 3	BH	BUILDING HEIGHT
EEM 4	E ALL	EEM (1 + 2 + 3)

2.5 LAST SIMULATION OF MODELLED BUILDING

In the last part of the simulation all the energy efficient methods used in the study has been implemented to the base building which is modelled with the help of the computer simulated tool. In case of WWR, base building block has been generated three times in three different ratios. In case of BO, the effect of base building block has constructed in three different orientation and finally BH. In case of BH, height of the building has been altered five times and their effect is analysed. Ultimately, all the best results from the three parameters which is discussed earlier has been applied to the base building block. This will give us the best result for making our building energy efficient.

3. RESULT AND DISCUSSION

3.1 SIMULATED AND MEASURED VALUES

After the validation it has been proved that, the simulated workshop air temperature is having a good similarity with the measured air temperature of the building taken for the work. After taking out the mean temperature difference of the simulated values and the measured value for 70 hours, it is

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found that there is only a difference of 0.8°C. Fig.3 shows the relation between the measured and simulated workshop air temperatures.

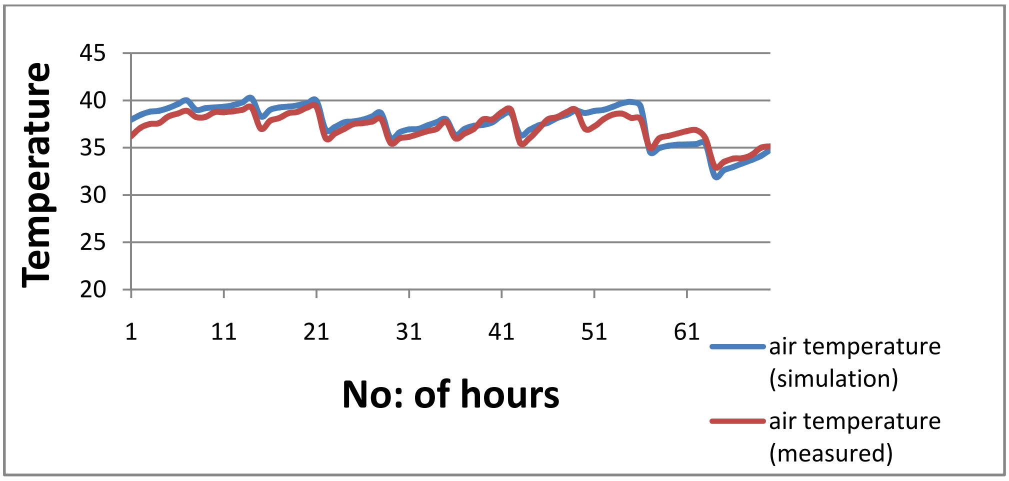

Figure 3: Relation between the measured and simulated workshop air temperature

From equations (1) – (4), it has been shown that the values for MBE and C_v (RMSE) are 2.1% and 2.6 which is less than 10% and 15%.

From equations (5) – (8) it has been proved that the U-value provided by the design builder is same as that of the manually calculated U-value.

3.2 OUTCOME OF BASE BUILDING

This study has focussed on three main results. These include:

- To reduce the solar heat gain of the workshop building
- To reduce the internal air temperature of the building
- To reduce the fanger PMV of the base building.

Before proceeding to the results of the building with the energy efficient methods, first of all we will discuss the various results of the base building with the help of graphs and tables.

Table: 3 Monthly deviations of solar heat gain, air temperature and fanger PMV of the base building

DATE	SOLAR HEAT GAIN (kwh)	AIR TEMPERATURE (°C)	FANGER PMV
01-01-2014	1962.755	20.72345	0.3191309

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01-02-2014	2247.158	23.97075	0.8053527
01-03-2014	2542.49	29.60572	1.782944
01-04-2014	2835.058	36.18935	3.114308
01-05-2014	2889.486	37.77656	3.61665
01-06-2014	2602.751	36.65581	3.459647
01-07-2014	2477.506	34.6869	3.048769
01-08-2014	2236.329	33.01054	2.673773
01-09-2014	2303.218	34.25325	2.839433
01-10-2014	2293.475	32.52247	2.35684
01-11-2014	2174.721	28.0597	1.529405
01-12-2014	1930.062	21.09869	0.4100095

3.3 EFFECT OF WWR

In this content the effect of implementing EEM 1 on the base building is analysed. In order to reduce the excess heating of buildings through solar gain, stringent building rules are necessary. So, one of the effective way to reduce the solar heat gain thereby reducing the internal temperature is to reduce the glazing area of the building. One of the best ways to minimise the glazing area is to reduce the window-wall ratio of the building. The building which has been used for this research work has an overall window wall ratio of 20%. In order to analyse the effect of WWR reducing the solar heat gain and internal temperature, we have varied the WWR three times. The WWR ratio has been checked for three times i.e. 15%, 25%, 30%. Table shows the annual solar heat gain, air temperature and fanger PMV comparison between the base building and building with 15%, 25% and 30% WWR.

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Table: 4 Annual solar heat gain, air temperature and fanger PMV comparison between base building and building with 15%, 25% and 30% WWR

METHODS	SOLAR HEAT GAIN (kwh)	DIFF. IN %	INTERNAL TEMP. (°C)	DIFF. IN %	FANG-ER PMV	DIFF. IN %
BB	28495.0	-	30.73446	-	2.167905	-
EEM 1A	16558.2	-41.8%	30.38496	- 1.14%	2.074496	-4.30%
EEM 1B	37028.7	23%	30.96271	0.74%	2.228305	2.71%
EEM 1C	57425.8	50.3%	31.34338	1.94%	2.323858	6.71%

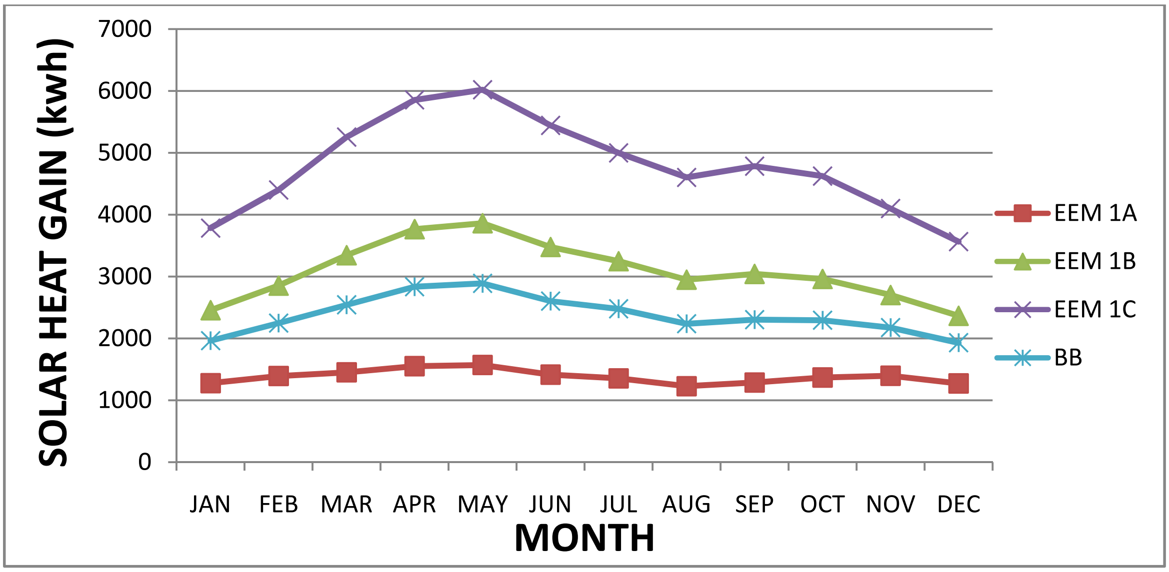

Figure 4: Solar heat gain comparison of base building and building with 15%, 25% and 30% WWR

From the graphs plotted and the table 4 it has been found that out of the three WWR used for the base building, the WWR with 15% has shown the best effect with the reduction in annual solar gain effect of 41.8%, enhancement in annual thermal comfort of 4.30% which is good advantage as this advantage is obtained without any use of insulation or change in orientation. Finally it has shown that by reducing the WWR to 15% an annual internal temperature reduction of 1.14% is obtained which is not a good advantage. But at the same time it has shown that by increasing the WWR above the WWR of the base

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building no advantage is obtained in any of the three cases. From the fig: it has been shown that during the summer time, further improvement in fanger PMV and air temperature is obtained by using WWR of 15% which is a good advantage as the building is workshop where all highly powered machine works are carried out.

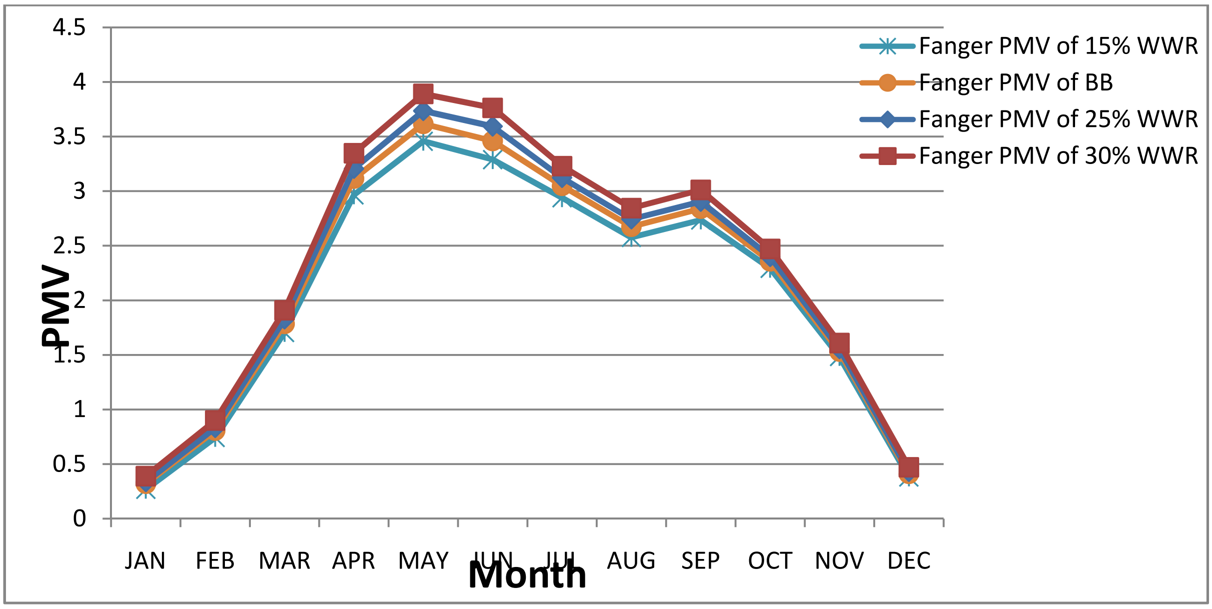

Figure 5: Fanger PMV comparison between the base building and building with 15%, 25% and 30% WWR

3.4 EFFECT OF BUILDING ORIENTATION

In the previous part of this study we have shown the effects on solar heat gain, internal air temperature and thermal comfort by minimising the WWR and increasing the WWR. Finally with the help of scattered graph and tables it has been proved that by reducing the WWR to 15%, best effect in solar heat gain, internal air temperature and thermal comfort is obtained and it is also sure that by decreasing the WWR again to 12% or 10% the solar heat gain can be further reduced but this will increase the use of artificial lighting which might increase the electricity consumption so another best way to reduce the solar heat gain, internal temperature and thermal comfort is to change the building orientation. In this part, the effect on these three will be examined by changing the orientation seven times i.e. south-west, south, south-east, east, north-east, north, north-west. The effect of each orientation on solar heat gain, air

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temperature and fanger PMV will show on the graph and tables. But it has been found that by changing the orientation of building to 45°, effect on internal air temperature is not that much significant. The internal air temperature variation mainly depends upon the material used for the construction and also on the wall facades **(2).** Therefore in this study, the internal air temperature effect has been analysed by changing the orientation to 90°.

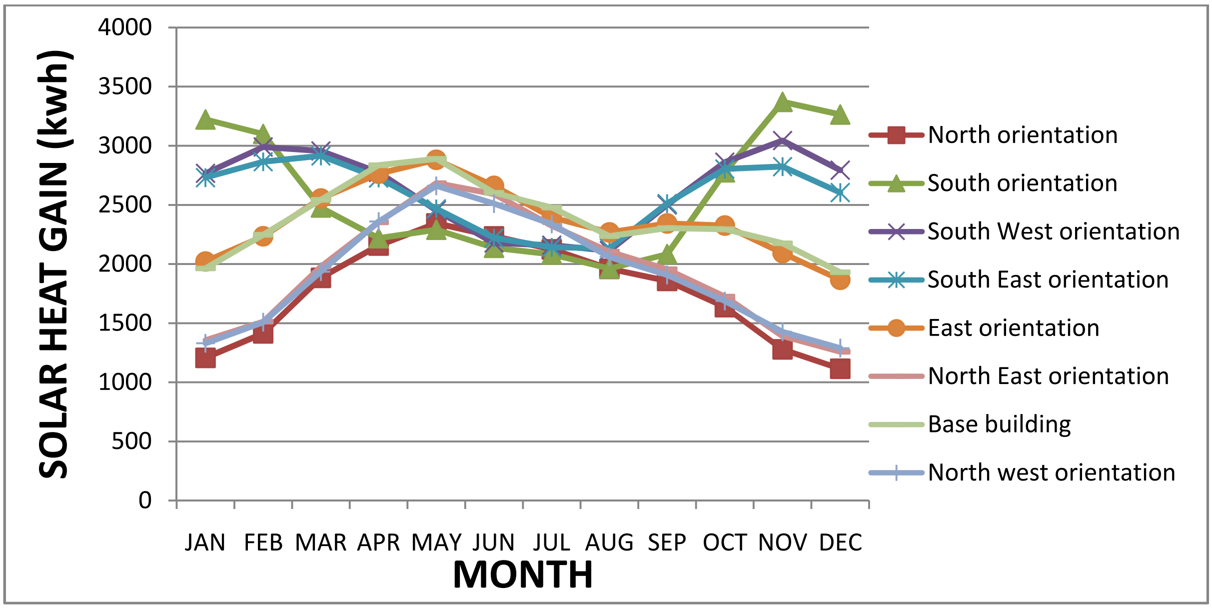

Figure 6: Solar heat gain comparison between the base building and building with various orientations

From the tables and the graphs plotted for the building with various orientations it has been understood that for solar heat gain building with south orientation is providing the best result for the winter season because during the winter season i.e from half of October to the month of march heat gain is very much important. It is seen clearly from the graph that during the summer season in composite climate like Rajasthan the heat gain is slightly lower for south orientation than the north orientation whereas all the other building orientations' heat gain is higher than the south and north orientation during the summer season. So, by making a comparison between the south and north orientation of the building it is understood that south orientation is preferred for the building rather than north orientation. In case of internal air temperature, it is understood that the base building and building with east

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orientation is having a massive similarity and both shows higher temperature than the south and north orientation so the building with east orientation is neglected and a comparison between south and north orientation of buildings show that during the months of winter season the temperature in south orientation is more than north orientation and a maximum of 1°C temperature difference is obtained which is a good result as it is providing without any use of thermal insulation in building whereas during summer season the air temperature in south orientation is slightly lower than north.

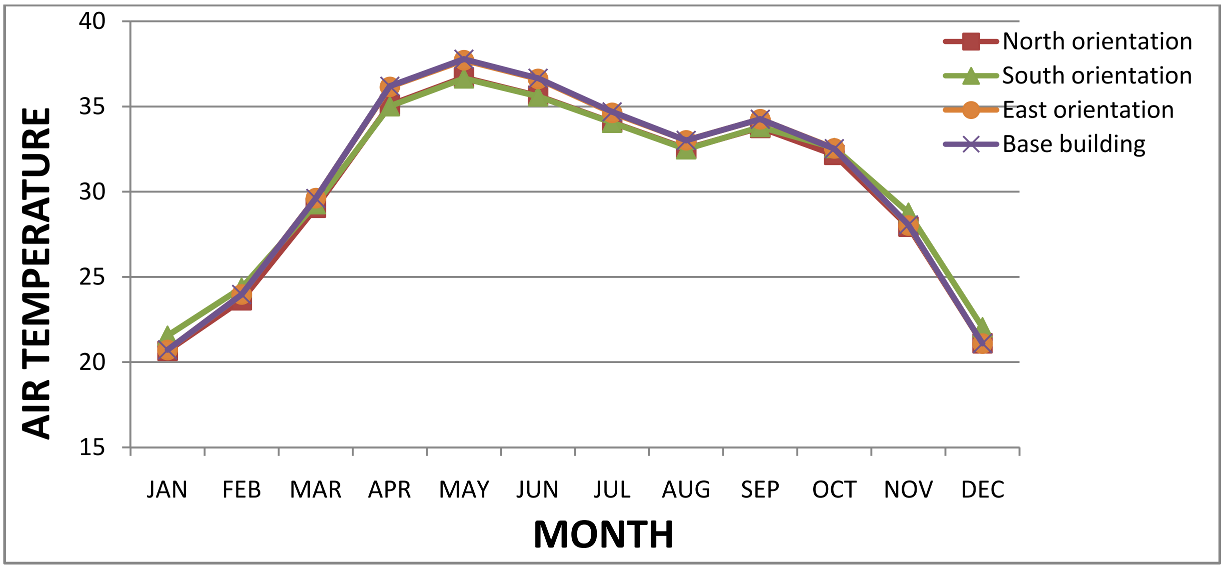

Figure 7: Air temperature comparison between the base building and building with various orientations

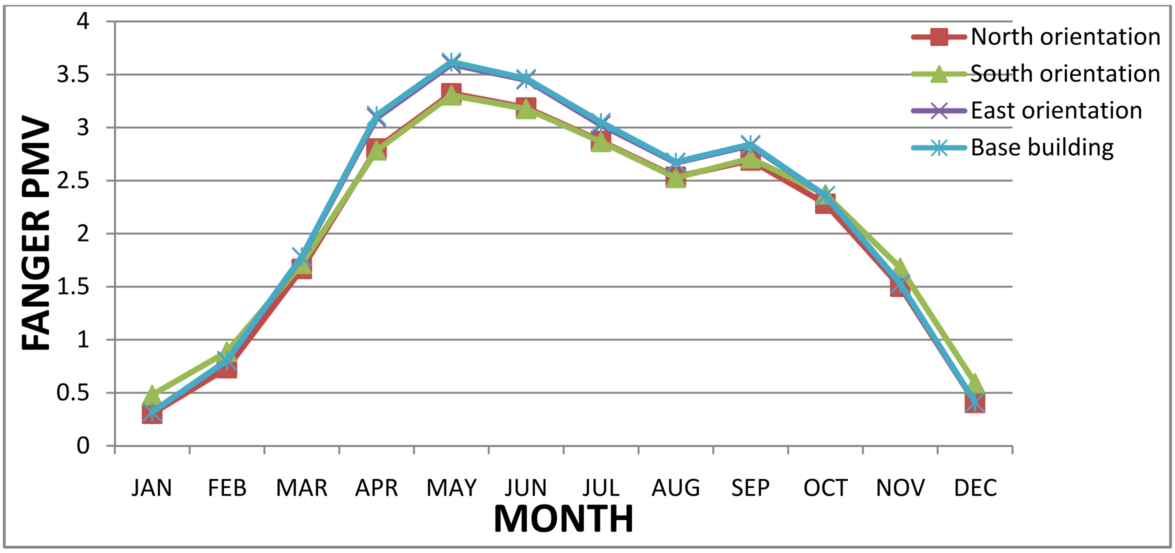

Figure 8: Fanger PMV comparison between the base building and building with various orientations

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3.5 BUILDING HEIGHT EFFECT

In this study the third EEM used is building height effect. From the table it has been proved that increasing or decreasing the building height has caused a negligible effect in case of solar heat gain and in case of internal air temperature decreasing the height by 5 feet has shown only a annual decrement of about 0.5% which is not an appreciable effect while increasing the building height has shown an annual air temperature decrement of 1.1%. Due to very slight enhancement in internal air temperature only small improvement in thermal comfort have been noticed but still increasing the building height has shown much more enhancement than decreasing the building height. So, increasing the building height has taken as the best of t Actually in case of a residential or office rooms the normal floor to floor height ranges between 10 feet and 12 feet but in this case the building is a college mechanical workshop building where the highly powered works are carried out so it is mandatory that the building height must be more than the normal floor to floor height of a residential rooms or office rooms otherwise the heat accumulation will be very high in case of buildings with machine works are performed.

TABLE: 5: EEM 3 AND DIFFERENCE IN ANNUAL AIR TEMPERATURE AND PMV IN COMPARISON TO BASE BUILDING

METHODS	**INTERNAL AIR TEMP. (°C)**	**DIFF. IN %**	**FANGER PMV**	**DIFF. IN %**
BB	30.73446	_	2.167	_
EEM 3A	30.58285	- 0.5%	2.131	- 1.7%
EEM 3B	30.40119	- 1.1%	2.088	- 3.6%

3.6 COMBINED EFFECT

From the results obtained for three EEM's used in this study, best results from each EEM is selected and those are implemented in the base building used in this research work. In case of EEM 1, best result is obtained in case of EEM 1A i.e. WWR with 15% whereas in case of

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EEM 2, best result is obtained in case of EEM 2B, i.e. building in south orientation has shown a good enhancement and finally in case of EEM 3, comparatively better result is obtained in case of EEM 3B, i.e. increasing the base building height of 20 feet to 25 feet.

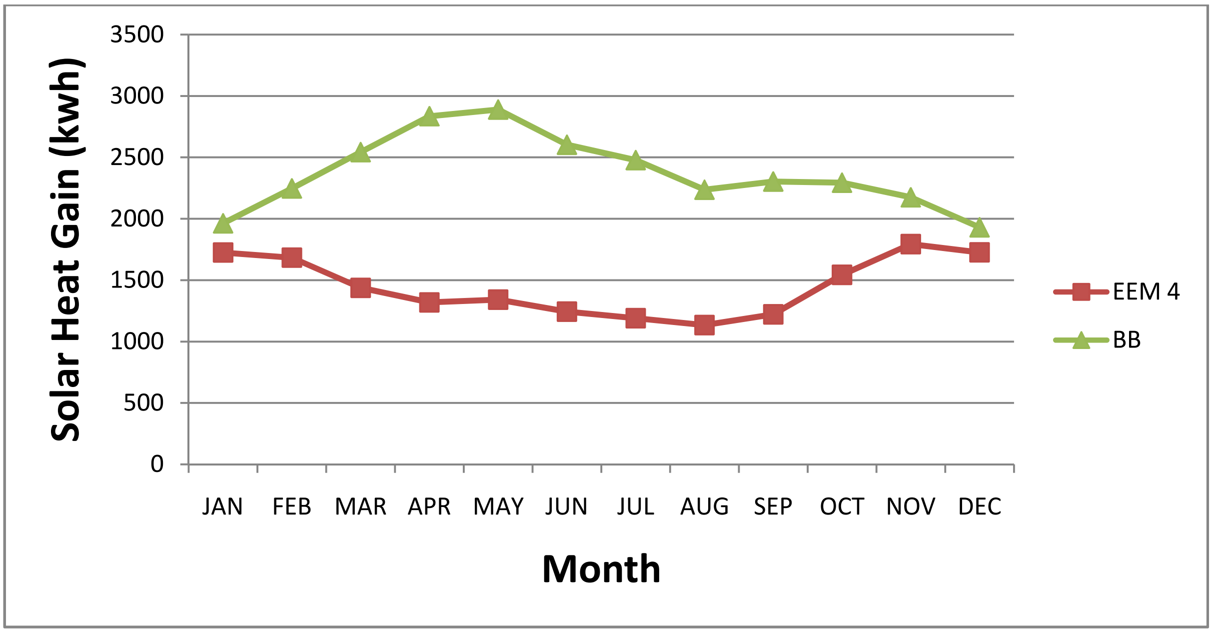

Figure 9: Solar heat gain comparison between the base building and building with EEM 4

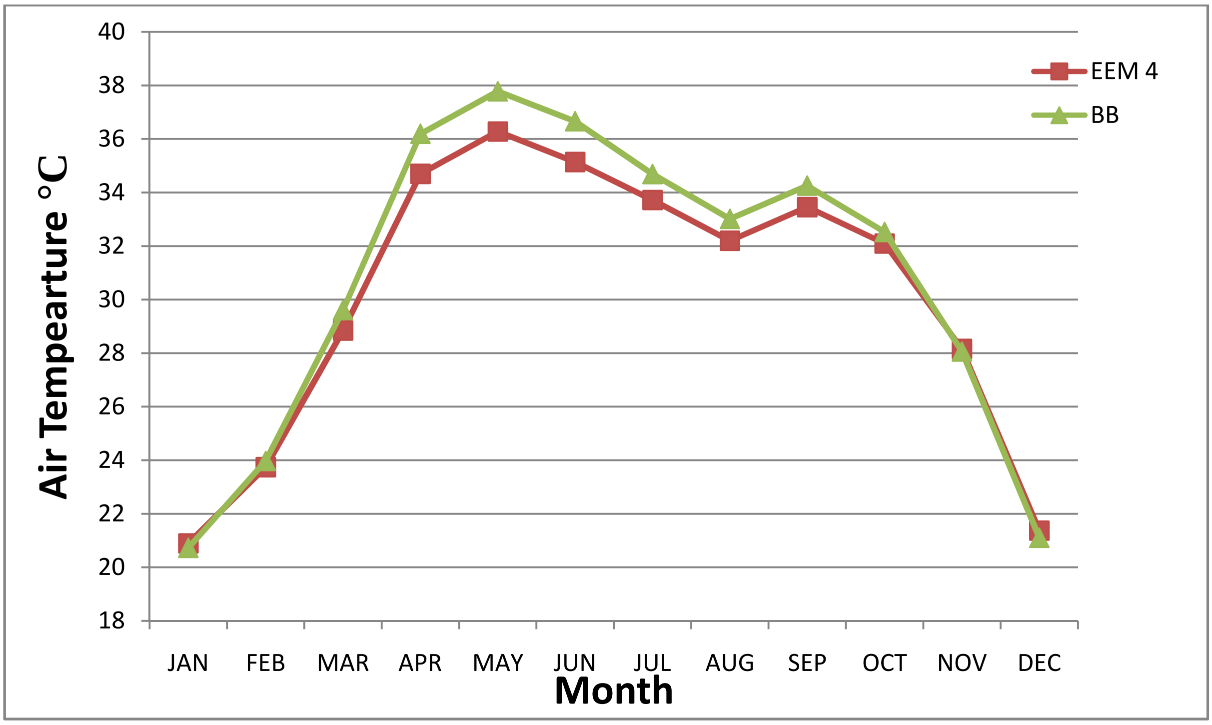

Figure 10: Air temperature comparison between the base building and building with EEM 4

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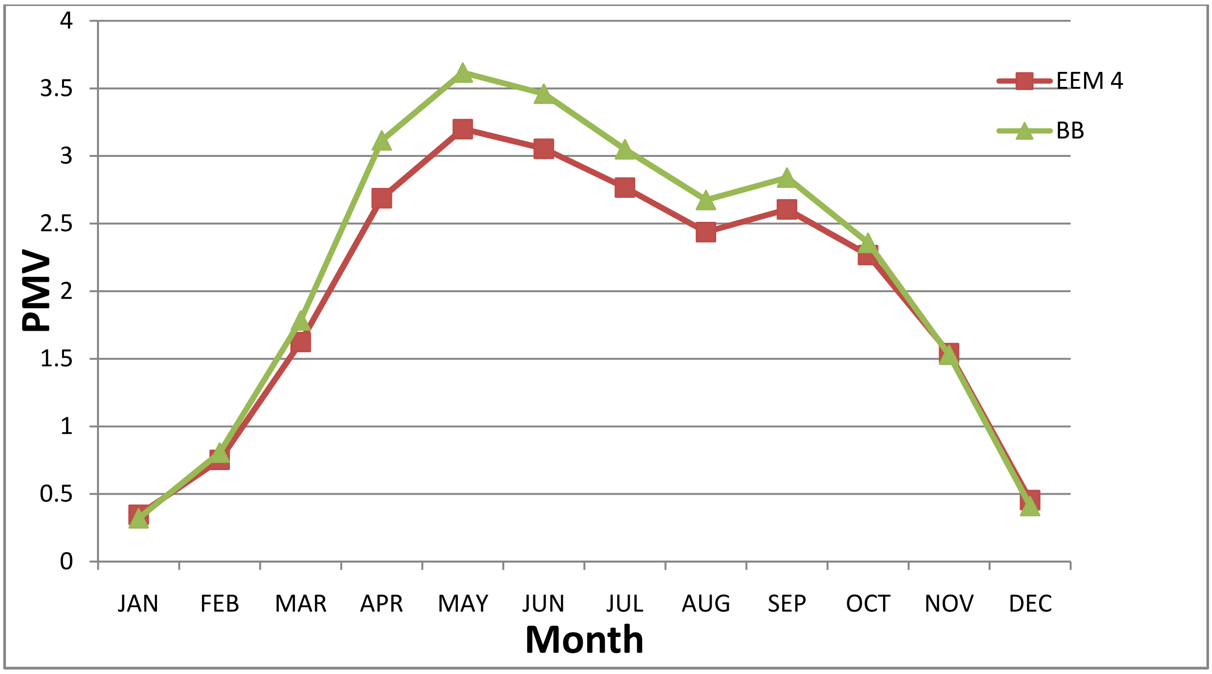

Figure 11: Fanger PMV comparison between the base building and building with EEM 4

Fig.9 shows that by implementing all the three energy efficient methods into a single building, a huge reduction in solar heat gain during the summer season can be obtained. This reduction in solar heat gain will help to reduce the internal temperature of the building as well as will increase the thermal comfort. Fig 10 shows that during the summer season the difference in internal air temperature is from 1 to 2°C and from fig. 11 an 8 – 9% increment in thermal comfort is achieved during the summer season which can be said as an appreciable achievement as it is acquired without any use of insulation or applying cool roofs.

4. CONCLUSION

The aim of this research work is to analyse the effect of building orientation, window-wall ratio and building height on solar heat gain, internal air temperature and thermal comfort of the building. From this study we came to a conclusion that, the solar heat gain through walls and windows are the main reason behind the excess heating of the building.

The important conclusions drawn from this study include:

➢ After varying the window-wall ratio to 15%, 25% and 30% , the best effect in case of solar heat gain, internal air temperature and fanger PMV, the best result is achieved in case of using **15% window-wall ratio.**

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- By varying the building orientation, it has been found that keeping the building in south orientation has shown the best effect in case of composite climatic conditions like Rajasthan. By keeping the building in south orientation, the solar heat gain and air temperature has increased for winter season whereas in case of summer season it has reduced. Fig. 5.5 shows the result for each orientation.
- The third EEM i.e. the building height has shown a negligible effect in case of solar of solar heat gain. But by increasing the building height from 20 feet to 25 feet a slight enhancement in case of air temperature and an appreciable improvement in thermal comfort is achieved.
- Finally, in this study we have analysed a combined effect i.e. implementing all the best effects, which we got from three EEMs, into the single building and it has shown that an appreciable enhancement in all the three cases i.e. solar heat gain, air temperature and fanger PMV is achieved. In case of solar heat gain a reduction of 39 – 40% is achieved and in case of air temperature a decrement of 2-3% is achieved whereas in case of fanger PMV a thermal comfort increment of 8-9% is achieved.

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